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(54) **METHOD AND DEVICE FOR ACTIVATING SEMICONDUCTOR IMPURITIES**

VERFAHREN UND VORRICHTUNG ZUM AKTIVIEREN VON VERUNREINIGUNGEN IN EINEM HALBLEITER

PROCEDE ET DISPOSITIF D'ACTIVATION D'IMPURETES DANS DES SEMI-CONDUCTEURS

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(73) Proprietor: **MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.**
Kadoma-shi, Osaka 571-8501 (JP)

(72) Inventors:
- **YOSHIDA, Akihisa**
  Kyoto-shi Kyoto 612-8469 (JP)
- **KITAGAWA, Masatoshi**
  Hirakata-shi Osaka 573-0073 (JP)
- **UCHIDA, Masao**
  Ibaraki-shi Osaka 567-0831 (JP)
- **KITABATAKE, Makoto**
  Nara-shi Nara 631-0076 (JP)
- **MITSUYU, Tsuneo**
  Hirakata-shi Osaka 573-1148 (JP)

(74) Representative: **Dempster, Benjamin John Naftel**
Withers & Rogers,
Goldings House,
2 Hays Lane
London SE1 2HW (GB)

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Description

TECHNICAL FIELD

[0001] The present invention relates to a mathod and an apparatus for activating a semiconductor impurity implanted in silicon carbide (SiC) and the like, for example, such a mathod and apparatus required in manufacturing semiconductor devices.

BACKGROUND ART

[0002] In a production of semiconductor devices utilizing silicon (Si), which is the most popular semiconductor material at present, generally, after adding an impurity in Si by an ion implantation and tha like method, the Si is heated to 900 °C to 1100 °C with the use of an electrical furnace, a flash lamp annaaler, and the like, to activate the impurity in the Si.

[0003] In recent years, a semiconductor device utilizing silicon carbide (SiC) has drawn considerable attention in the industry since such a device is excellent in electric power characteristics (high breakdown voltage and high current-carrying capacity), high-frequency characteristics, and resistance in an environment of use. However, the ion implantation and activation of SiC involve many difficulties in comparison with those of Si. In order to overcome such difficulties, several techniques in the impurity activation have been suggested. An example of such techniques is that an impurity is added when forming an SiC film, an ion implantation is carried out under a high temperature of about 500 °C to 1000 °C, and thereafter, as disclosed in T. Kimoto, et al., *Journal of Electronic Materials*, Vol. 25, No. 5, (1996) pp. 879-884, an impurity is activated by a heat treatment at a high temperature of 1400 °C to 1600 °C.

[0004] However, such methods of impurity activation by a heat treatment require a step of heating Si and the like semiconductor material with the use of electrical furnace and the like. Consequently, a relatively long tima is necessary for the activation, and therefore it is rendarad difficult to increase the productivity. Such drawbacks become more conspicuous in the case of using SiC since a further higher temperature is required in the heat treatment. Moreover, in the case of SiC, regarding a p-type dopant, it is difficult to form a semiconductor layer in which the p-type dopant element is activated to a high degree.

[0005] In view of such drawbacks, for example, Japanese Unexamined Patent Publication No. 7-022311 discloses such a method of an impurity activation as described in the following. According to this, a laser annealing is conducted by irradiating with a-laser light an amorphous Si film in which concentrations of carbon, nitrogen, and oxygen are made to be lower than certain values, in order to form a mixed region in which an amorphous region and a solid-phase ordered region are present together without fusing the amorphous Si film. Then, impurity ions are implanted into the amorphous Si film, and thereafter laser annealing is carried out by irradiating the Si film with a laser light having a wavelength of 248 nm to make an impurity region to be a semi-amorphous state. However, although it is disclosed in the Publication No. 7-022311 that a carrier mobility can be improved by the method when compared with an amorphous Si, a laser annealing for the semiconductors other than the amorphous Si is not mentioned.

[0006] A laser light conventionally used for a laser annealing for such a crystallization (activation) of a semiconductor has been a lasar light having a wavelength shorter than a wavelength causing a band edga absorption, such as an excimer lasar, as described specifically in Y. Morita, et al., *Jpn. J. Appl. Phys.*, Vol. 28 No. 2, (1989) pp. L309- L311. In the casa of using a laser light having such a wavelength, electrons in the atoms constituting a semiconductor are excited and ionized by tha energy of the laser light, and part of the energy of the electrons is convarted into a lattice vibration of the atoms, transiently heating the semiconductor to a high temperature and thus promoting the crystallization (activation) of the semiconductor.

[0007] However, in such a prior art impurity activation by a laser annealing as described above, a laser apparatus with a relatively large output power is required since efficiency in energy utilization is low, and therefore the manufacturing cost tends to be increasad. Furthermore, according to such a method, it is not easy to carry out the activation of impurity with high reliability and to produce samiconductor devices with desirable characteristics. In particular, the production of semiconductor devices with desirable characteristics is difficult in the activation of p-typa impurities in the case of SiC.

DISCLOSURE OF THE INVENTION

[0008] In view of the foregoing drawbacks in the prior art, it is an object of the present invention to provide a method of activating a semiconductor impurity in which the activation of the impurity can ba carried out with high efficiency and reliability even whan a laser apparatus with a relatively small output powar is used.

[0009] This and other objects are accomplished in accordance with the present invention by providing a method for activating a semiconductor impurity in a semiconductor comprising a major semiconductor element and an impurity element by irradiating the semiconductor with a light, the light having a longer wavelength than a wavelength causing a band edge absorption of the semiconductor. Tha light has such a wavelength that a resonance absorption is caused by a characteristic vibration in a bond of an element constituting the major semiconductor element and the impurity element.

[0010] In the cases of prior art activation methods utilizing a light having a wavelength shorter than a wave-

length causing a band edge absorption of a semiconductor, electrons in the atoms constituting the semiconductor are excited and ionized by the energy of the light, and part of the energy of the electrons is converted into the energy for a lattice vibration of the atoms. The semiconductor is thereby heated transiently to a high temperature, and thus the impurity is activated. On the other hand, the present inventors have found that, by irradiating a semiconductor with a light having a longer wavelength than a wavelength causing a band edge absorption of the semiconductor, a lattice vibration between the impurity element and the semiconductor element can be directly caused, and thereby the impurity can be activated. Therefore, according to the present invention, such advantageous effects are achieved that the efficiency in the activation is made to be excellent, that a laser apparatus with a small output power can be employed, and that a desirable impurity activation can be readily carried out.

[0011] More specifically, since the major semiconductor element is silicon carbide and the impurity element is one of aluminum, boron, and gallium, a light having a wavelength of 9 μm to 11 μm, which is longer than a wavelength causing the band edge absorption (in the case of 6H-SiC, approximately 3 eV: up to 0.41 μm), may be employed, in order to readily produce a p-type silicon carbide semiconductor with desirable characteristics. In particular, in the case of aluminum, it is more preferable to employ a wavelength of 9.5 μm to 10 μm.

[0012] According to another aspect of the invention, in irradiating a semiconductor with a laser light having such a wavelength as described above, the laser light may be focused on a focal point adjacent to a surface of the semiconductor, and the focal point of the laser light may be made to be a point between a light source of the laser light and the surface of the semiconductor having a predetermined distance from the surface of the semiconductor. More specifically, in irradiating a semiconductor with a laser light having such a wavelength as described above, the laser irradiation may be carried out by detecting a plume caused in the case where the focal point of the laser light is brought to a position adjacent to the surface of the semiconductor from a direction of the light source of the laser light, and controlling the focal point of the laser light to be such a position that the plume starts to be detected.

[0013] By setting and controlling the focal point as described above, the degree of the activation is further improved easily.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

Fig. 1 is a diagram showing the steps of producing a semiconductor substrate in accordance with an embodiment of the present invention.

Fig. 2 is a graph showing a concentration of impurity ions in an impurity-doped semiconductor substrate in accordance with an embodiment of the present invention.

Fig. 3 is a diagram schematically showing a construction of a laser anneal system.

Fig. 4 is a graph showing a dependence 'on a focal point of a photoluminescence spectrum of an SiC film in a semiconductor substrate laser-annealed in accordance with an embodiment of the present invention.

Fig. 5 a graph showing a dependence on a laser light wavelength of a photoluminescence spectrum of an SiC film in a semiconductor substrate laser-annealed in accordance with an embodiment of the present invention.

Fig. 6 is a diagram showing the steps of manufacturing an SiC diode accordance with an embodiment of the present invention.

Fig. 7 is a graph showing electrical characteristics of an SiC diode accordance with an embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

[0015] Now, with reference to the figures, there is described an example in which aluminum (Al) ions implanted into silicon carbide (SiC) as an impurity are activated.

Steps of Manufacturing a Semiconductor Substrate

[0016] First, referring to Fig. 1, an outline of fabrication steps of a semiconductor substrate, including a step of laser annealing, is detailed below.

(1) As shown in Fig. 1 (a) and (b), an SiC thin film 2 composed of a single crystalline 6H-SiC (hexagonal silicon carbide) is epitaxially grown on a surface of an SiC substrate 1 composed of a single crystalline 6H-SiC by utilizing a sublimation method. The detail regarding methods and conditions for forming the SiC thin film 2 is not included herein, since known methods and conditions can be employed therefor. The SiC substrate 1 and the SiC thin film 2 are formed to be n-type by doping nitrogen (N) with a concentration of 10^{18} cm^{-3} by adding a nitrogen gas (N_2) when growing the crystals. It is noted that the SiC substrate 1 and the SiC thin film 2 is not limited to the ones composed of 6H-SiC, and other crystal structures may be likewise employed. In addition, not only the foregoing sublimation method, but also other methods such as a CVD method and the like may be employed in growing a single crystal to form the SiC thin film 2. The doping of N may be omitted depending on the types of semiconductor devices to be produced using the semiconductor formed according to the present invention.

(2) As shown in Fig. 1 (c), Al ions 3 are implanted

into the SiC thin film 2 by ion implantation to form a p-type impurity-added layar (doped layer) 4 in the vicinity of a surface of the SiC thin film 2. The ion implantation is, more perticularly, carried out at e temperature of 800 °C through the following three stages of:

(a) an acceleration energy of 130 keV and e dose of 1.22×10^{15} cm^{-2},
(b) en accaleration energy of 80 keV end a dose of 3.9×10^{14} cm^{-2}, and
(c) an acceleration energy of 40 keV and a dose of 3.9×10^{14} cm^{-2}, so as to form tha impurity-added layer 4 in which a region with an Al concentration of 10^{20} cm^{-3} is distributed down to a depth of approximately 200 nm from tha surface of the SiC thin film 2, as shown In Fig. 2.

For an impurity for forming the p-type impurity added layer 4, boron (B), gellium (Ga) and the like may be used other then Al. However, regarding the doping to an SiC thin film; it is praferable to use Al In the casa of p-type with a low impurity leval. In addition, it is also possible to form an n-type impurity added layer 4 by using phosphorus (P) and tha like. In this case, Al and the like may be added when growing the crystals of the SiC substrate 1 and the SiC thin film 2 In place of adding N as described above. In eddition, ragerding such conditions of tha ion implentation as e temperature et the Implantation, an accelaration anergy and a concantration In the implantation, and a selection of using whether one stage or multistages for implantation, such conditions may be determined depending upon the constructions, the thickness of the doped layer, and the like of tha semiconductor devices to be produced using the semiconductor formed according to tha present Invantion. A temperature In tha Implantation may be at room temperature, but it is more preferable to be at 500 °C or higher, sinca the impurity ere thereby activated mora aasily in the subsequent laser annaaling step. Naturally, othar various known methods of ion implantation may be employed.

(3) As shown In Fig. 1 (d), the impurity added layer 4 Is irradiated with a lasar light 5 having a wavalength of the infrared radiation range scanning horizontally and vertically with a predetermined scanning frequency, so as to form an activated doped layer 6 in which the added impurity is evenly activated in the whola ragion. The detailed description regarding this activation is included in the following.

Laser Anneal System

[0017] Now, tha description details e laser anneal system.

[0018] As schematically shown in Fig. 3, the laser anneal system comprises a chamber 21 and a free-electron laser 22. In the chamber 21, an SiC substrate 1 in which an SiC thin film 2 is formed and Al is Implanted (This substrate is hereinafter referred to es simply an "SiC substrate 1.") is to be disposed, and a wavelangth of laser oscillation of the free-electron laser 22 is made to be variable. In the chambar 21, there are provided an optical window 7, a raflector mirror 8, a lens 9 for focusing and adjusting the laser light, a galvanomatar mirror 10 for reflecting the laser light end scanning, end e sample table 11 for disposing the SiC substrate 1. The optical window 7, the reflector mirror 8, and tha lens 9 are made from, for example, ZnSe. The sampla table 11 has such a construction that the SiC substrate 1 can be moved in a vertical direction and horizontal direction in Fig. 3 by means of a sample tabla moving mechanism 16 provided with a piezoelectric actuetor or a stepping motor and tha lika (not shown). In tha vicinity of tha sample table 11, a light detector 15 for detecting e sperk-like light emission (plume) 14, which is generated from the surface of the SiC substrate by a laser light irradiation, is provided, and according to tha result of tha detection, tha movement of tha sample tebla moving mechanism 16 is controlled to move tha sample table 11 in the upward or downward direction.

Detail of Laser Annealing Treatment

[0019] Now, a laser annealing traatment utilizing the foregoing laser anneel system is detailed below.

[0020] In accordance with this lasar annaaling traatment, a position of a focal point of the laser light 5 and a wavelength of the laser light 5 are appropriately set in order to achieve a desirable impurity activation.

[0021] Firstly, an adjustment of the focal point is detailed. Tha wavelangth of tha lasar light 5 was sat at 10.2 µm, and tha focal point of the lasar light 5 was set at various positions ranging from 1.5 mm upward to -2.0 mm inward (a backside of the SiC substrete 1) with respect to tha surface of the SiC substrate 1, to carry out tha impurity activation. Regarding each of the resulting SiC substrates 1, in order to confirm the degree of impurity activation, a measurement of photoluminescence spectrum was carriad out with a subjected sample temperature of 8 K (-265 °C) with the use of He-Cd laser (wavelength: 325 nm) as an excitar light. The results of the measurement are shown in Fig. 4. It is noted thet, in Fig. 4, a light emission observed in the vicinity of approximately 2.6 eV (wavelength: 480 nm) is a photoluminescence by the recombination of donor (D) - acceptor (A) pair (DA pair light emission) resulting from the activated impurity elements in the SiC substrate 1, and that the more tha activatad impurity is, the larger the intensity of the DA pair light emission becomes. As seen from the results, when the focal point of the leser light 5 is slightly (0.5 mm to 1.0 mm) above the surfece of the SiC substrate 1 (represented by the plots ○ end Δ in Fig. 4), the strongest DA pair light amission is observed, and

it provas that the impurity activation is most efficiently carried out under such conditions. On the other hand, when the focal point is sat inwardly with respect to the surface of the SiC substrate 1 (represented by the plots ●, ▲, ■, and ▼in Fig. 4), the intensity of the DA pair light emission is rendered small. When the focal point is slightly inside the surface of the SiC substrate 1 (represented by the plots ● and ▲ in Fig.4), tha surface of the SiC substrate 1 wes blackened, end it is considered that the surface of the SiC substrate 1 wes modified or deteriorated. From the foregoing, it is concluded thet a desirable activation can be echieved by making the focal point of the laser light 5 slightly abova tha surface of the SiC substrate 1.

[0022] Such control of the focal point can be carried out, for exampla, according to the following manner. That is, the state of the focal point of the laser light 5 baing slightly above the surface of the substrate 1 corresponds to the state in which the plume 14 starts to be generated by the irradiation of the laser light 5. Therefore, by detecting the occurrence of the plume 14 with the light detector 15 end accordingly carrying out a feedback control so thet the state of the plume starting to be generated is maintained by moving the SiC substrate 1 with the sample table moving mechanism 16, the irradiated surface is controlled to be placed in the most suitable position to achieve a desirable activation. In order to prevent the modification or deterioration of the SiC subetrate 1 caused by the irradiation of the laser light 5, it is preferable that the focal point be at first set at a position away from the surface of the SiC substrate 1 and thereafter be brought close to the SiC substrate 1.

[0023] It is to be noted that a method of controlling the focal point is not limited to such a method as described above. For example, the control may be carried out by detecting the position of the surface of the SiC substrate 1 by means of a position sensor. In addition, when the distance between the focal point end the surface of the SiC substrate can be maintained constantly, the position of the sample table 11 may be determined in advance and need not to ba controlled during the laser annealing.

[0024] In addition, by controlling the focal point in such a manner as described above, an intensity of laser light irradiation to the SiC substrate 1 can ba readily controlled. However, the intensity of the laser light irradiation mey be controllad by modulating the laser light based on the results of the detection of the plume and the like method.

[0025] Sacondly, control of the wevelength of the laser light 5 is detelled. A wavelength of the laser light 5 wes set at verious wavelengths ranging from 10.64 μm to 9.43 μm, to carry out the impurity activation, and a photoluminescence spectrum was measured regarding each of the resulting SiC substrates 1 in the same manner as in the above example where the focal point was varied. The results of the maasurement are shown in Fig. 5. (It is to be noted that, in Fig. 5, for the sake of clarity, an interval of 0.05 scale in the direction of the y-axis is placed between each spectrum corresponding to each of the wavelangths.) As apparent from Fig. 5, when the wavelength of the leser light 5 is in the range of 9-11μm, more particularly in the range of 9.5- 10 μm, the intensity of the DA pair light emission is high, and therefore the effect of the activation by Al is large.

[0026] In the case of SiC, the absorption wavelengths corresponding to TO phonon end LO phonon in lattice vibration of Si-C are 12.6 μm and 10.3 μm respectively, and the absorption wevelength of Si-N is 11.9 μm. However, es shown in Fig. 4, the maximum DA pair light emission was obteined in the cases of the leser light with a wavelength of 9.8- 9.6 μm. Therefora, it is considered that an absorption in the bond of Si and the impurity element Al, or C and the impurity element Al, has a great influence on the activation of Al.

[0027] In prior art activation methods, a light such as an excimer laser, which has a shorter wevelength than a wavelength that causes a band edge absorption in SiC (in the case of 6H-SiC, approximately 3 eV: up to 0.41 μm), has been employed in order to provide energy to the electron system in the subjected semiconductor. In contrast, a method in accordance with tha present invention employs a light having e longer wavelength than the wavelength that causes the band edge absorption, particularly, a light having such a wavelength that en ebsorption for a bond of an impurity element and an element composing e semiconductor is caused. By employing such a light, activation by directly exciting the lattice vibration between an impurity element and an element constituting a semiconductor is made possible, and therefore such advantageous effects are achieved that the degree of an activation can be reedily improved with high efficiency and that a laser system with a small output power can be employed.

[0028] It is noted that the above values are the examples in the case of employing SiC and Al, and when other impurity elements are employed, a light having a wavelength based on the theory as described above may be used depanding upon the compositions.

[0029] Further, the above-described example may include such steps as a step of enclosing an inert gas such as argon (Ar) and the like in tha chamber 21 and thereafter carrying out the laser annealing in such atmosphere, a step of heating the SiC substrate 1 to a temperature of approximately 1000 °C or lower, and a step of cooling the SiC substrate 1. It is preferable to add such steps to the above example in that the effects of the invention are further increased, and the controllebility is further improvad.

[0030] The materiel is not limited to a singla crystal material, and the same effects are also attained in the case of employing amorphous semiconductor materials and the like.

[0031] Although a free-alactron laser is used in the above example in order to make a comparison in various wavelengths, a laser system with a fixed wavelength mey ba used insofar as a predetermined wavelength as

described above is obtained. In particular, since a relatively long wavelength is utilized, the productivity can be readily increased by using a CO_2 laser and the like.

Semiconductor Device

[0032] Now, there is explained an example of an SiC diode utilizing the SiC in which impurity ions are implanted and activated in the same manner as in the above example.

[0033] Fig. 6 shows a schematic diagram of the steps of producing an SiC diode according to a method of doping impurities in accordance with the present invention.

(1) As shown in Fig. 6(a), an insulation layer (oxide layer) 32 is formed on the whole surface of an n-type SiC substrate 31 by a thermal oxidation, CVD, sputtering, and the like method, and thereafter an aperture 32a is formed by a photolithography and etching. For the insulation layer 32, an oxide layer, a nitride layer, or a combination layer of an oxide layer and a nitride layer may be used. The insulation layer 32 may be omitted depending upon the construction of the devices to be produced.
(2) As shown in Fig. 6(b), using the insulation layer 32 as a mask, Al ions 33 are selectively implanted, and an Al implanted layer 34 is thereby formed.
(3) As shown in Fig. 6(c), by irradiating a laser light 35 having a wavelength of 9.8 μm, a p-type doped layer 36 in which the impurity is activated is formed.
(4) As shown in Fig. 6(d), an aperture 32b is formed on the back surface of the insulation layer 32. Thereafter, as shown in Fig. 6(e), a nickel (Ni) layer is deposited, and an n-type ohmic electrode 37 is formed by etching and heating treatment.
(5) As shown in Fig. 6(f), an Al layer is deposited over the surface on which the p-type doped layer 36 is formed, and thereafter an ohmic electrode 38 is formed by etching and heat treatment.

[0034] Fig. 7 shows the characteristics of a diode made in accordance with the foregoing steps. The dashed line in the same figure shows the characteristics of a prior art diode made by an impurity activation by a heat treatment at 1500 °C, as explained in the background art herein. As shown in Fig. 7, it is understood that, according to the present invention, an advantageous diode having an excellent breakdown voltage characteristic and the like characteristics is achieved without such a high temperature heat treatment at 1000 °C or higher.

[0035] Although an example of forming a diode is explained herein, various devices such as transistors and FETs (field-effect transistors) can be produced by the same doping (activation) method as described above, for example, with appropriately selecting device constructions and masks.

INDUSTRIAL APPLICABILITY

[0036] The present invention can be realized according to the examples described thus far, and exhibits advantages as described below.

[0037] Specifically, by utilizing a light having a wavelength longer than a wavelength by which a band edge absorption is caused in the semiconductor, and more specifically a light having approximately a wavelength by which a resonance absorption is caused by the characteristic vibration in the bond of the impurity element and the elements constituting the semiconductor, it is made possible to carry out an impurity activation with a high efficiency and high reliability, even when a laser device with a relatively small output power is employed. In particular, an activation of a p-type impurity in SiC, which has been difficult, can be carried out with an extremely high efficiency.

[0038] Accordingly, the present invention is useful, since it is applicable to such fields as fabrication of semiconductor devices and the like.

Claims

1. A method of activating a semiconductor impurity by irradiating a semiconductor comprising a major semiconductor element and an impurity element with light to activate the impurity element, wherein:

    said major semiconductor element is silicon carbide;
    said impurity element is one of aluminium, boron, and gallium;
    said light has a wavelength that is longer than a wavelength causing band edge absorption of the semiconductor;
    said wavelength is such that resonance absorption is caused by a characteristic vibration in a bond of an element constituting said major semiconductor element and said impurity element; and
    using said light, said impurity element is activated by selectively vibrating a bond between said impurity element and said element constituting said major semiconductor element in said semiconductor.

2. A method of activating a semiconductor impurity according to claim 1, in which said light is applied after said impurity element is implanted into said major semiconductor element.

3. A method of activating a semiconductor impurity according to claim 1, in which said semiconductor is formed by implanting said impurity element in a thin film comprising said major semiconductor element or in a substrate comprising said major semicon-

ductor element.

4. A method of activating a semiconductor impurity according to claim 1, 2, or 3 in which said light has a wavelength of 9.5 µm to 10 µm.

5. A method of activating a semiconductor impurity according to any preceding claim, in which said light is laser light.

6. A method of activating a semiconductor impurity according to claim 5, in which:

   said laser light is focused on a focal point adjacent to a surface of the semiconductor; and said impurity element in a predetermined region in the semiconductor is activated by scanning the semiconductor with the laser light.

7. A method of activating a semiconductor impurity according to claim 5, in which:

   said laser light is focused on a focal point adjacent to a surface of the semiconductor; and the irradiation intensity of the laser light is controlled by controlling the distance between the focal point and the surface of the semiconductor.

8. A method of activating a semiconductor impurity according to claim 5, in which:

   said laser light is focused on a focal point on or sufficiently close to a surface of the semiconductor such that a plume is caused, and irradiation of the laser light is carried out by detecting a plume caused in the case where irradiation intensity of the laser light is increased, and controlling the irradiation intensity to be such an intensity that the plume starts to be detected.

9. A method of activating a semiconductor impurity according to claim 5, in which:

   said laser light is focused on a focal point adjacent to a surface of the semiconductor; and irradiation of the laser light is so controlled that the focal point of the laser light is a position between the light source of the laser light and the surface of the semiconductor, the position having a predetermined distance from the surface of the semiconductor.

10. A method of activating a semiconductor impurity according to claim 5, in which:

   said laser light is focused on a focal point on or sufficiently close to a surface of the semiconductor such that a plume is caused, and irradiation of the laser light is carried out by detecting a plume caused in the case where irradiation intensity of the laser light is increased, and controlling the laser light to be focused on such a position that the plume starts to be detected.

11. A method of activating a semiconductor impurity according to any preceding claim, in which only a predetermined region in the semiconductor is selectively irradiated with said light by using a member for masking.

12. A method of activating a semiconductor impurity according to any preceding claim, in which said light has a wavelength of 9.6 to 9.8 µm.

Patentansprüche

1. Verfahren zur Aktivierung einer Halbleiterstörstelle durch Bestrahlung eines Halbleiters, der aus einem Haupthalbleiterelement und einem Störstellenelement besteht, mit Licht, um das Störstellenelement zu aktivieren, wobei:

   das Haupthalbleiterelement Siliciumcarbid ist;

   das Störstellenelement eines der Elemente Aluminium, Bor und Gallium ist;

   das Licht eine Wellenlänge besitzt, die länger ist, als eine Wellenlänge, die Bandkantenabsorption des Halbleiters verursacht;

   die Wellenlänge derart ist, dass Resonanzabsorption durch die charakteristische Schwingung einer Bindung eines den Halbleiter aufbauenden Elements mit dem Störstellenelement verursacht wird;

   durch Gebrauch des Lichts das Störstellenelement durch selektives Schwingen einer Bindung des Störstellenelements mit dem das Haupthalbleiterelement aufbauenden Element im Halbleiter aktiviert wird.

2. Verfahren zur Aktivierung einer Halbleiterstörstelle nach Anspruch 1, bei dem das Licht angewandt wird, nachdem das Störstellenelement in das Haupthalbleiterelement implantiert wurde.

3. Verfahren zur Aktivierung einer Halbleiterstörstelle nach Anspruch 1, bei dem der Halbleiter durch Implantierung des Störstellenelements in einen dünnen Film, der aus dem Haupthalbleiterelement be-

steht, oder in ein Substrat, das aus dem Hauptthalbleiterelement besteht, gebildet wird.

4. Verfahren zur Aktivierung einer Halbleiterstörstelle nach Anspruch 1, 2 oder 3, bei dem das Licht eine Wellenlänge von 9.5 µm bis 10 µm besitzt.

5. Verfahren zur Aktivierung einer Halbleiterstörstelle nach einem der voranstehenden Ansprüche, bei dem das Licht ein Laserlicht ist.

6. Verfahren zur Aktivierung einer Halbleiterstörstelle nach Anspruch 5, bei dem:

das Laserlicht auf einen Brennpunkt fokussiert wird, der an der Oberfläche des Halbleiters liegt; und

das Störstellenelement in einem vorbestimmten Bereich im Halbleiter durch Abtasten des Halbleiters mit dem Laserlicht aktiviert wird.

7. Verfahren zur Aktivierung einer Halbleiterstörstelle nach Anspruch 5, bei dem:

das Laserlicht auf einen Brennpunkt fokussiert wird, der an der Oberfläche des Halbleiters liegt; und

die Strahlungsintensität des Laserlichts durch Steuerung der Distanz zwischen dem Brennpunkt und der Oberfläche des Halbleiters gesteuert wird.

8. Verfahren zur Aktivierung einer Halbleiterstörstelle nach Anspruch 5, bei dem:

das Laserlicht auf einen Brennpunkt fokussiert wird, der an oder hinreichend nahe der Oberfläche des Halbleiters liegt, so dass ein künstliches Echo erzeugt wird; und

Bestrahlung mit dem Laserlicht ausgeführt wird, und zwar durch Detektieren eines künstlichen Echos, das in dem Fall verursacht wird, bei dem die Bestrahlungsintensität des Laserlichts gesteigert wird, und durch Regelung der Bestrahlungsintensität auf solch eine Intensität, dass das künstliche Echo beginnt, detektiert zu werden.

9. Verfahren zur Aktivierung einer Halbleiterstörstelle nach Anspruch 5, bei dem:

das Laserlicht auf einen Brennpunkt fokussiert wird, der an der Oberfläche des Halbleiters liegt; und

Bestrahlung mit dem Laserlicht so gesteuert wird, dass der Brennpunkt des Laserlichts zwischen die Lichtquelle des Laserlichts und die Oberfläche des Halbleiters positioniert wird, wobei die Position einen vorbestimmten Abstand von der Oberfläche des Halbleiters besitzt.

10. Verfahren zur Aktivierung einer Halbleiterstörstelle nach Anspruch 5, bei dem:

das Laserlicht auf einen Brennpunkt fokussiert wird, der an oder hinreichend nahe der Oberfläche des Halbleiters liegt, so dass ein künstliches Echo erzeugt wird; und

Bestrahlung mit dem Laserlicht ausgeführt wird, und zwar durch Detektieren eines künstlichen Echos, das in dem Fall verursacht wird, bei dem die Bestrahlungsintensität des Laserlichts gesteigert wird, und durch Steuern des Laserlichts derart, dass es an solch eine Position fokussiert wird, dass das künstliche Echo beginnt, detektiert zu werden.

11. Verfahren zur Aktivierung einer Halbleiterstörstelle nach einem der voranstehenden Ansprüche, bei dem nur ein vorbestimmter Bereich im Halbleiter selektiv mit dem Licht durch Verwendung eines Elements zur Maskierung bestrahlt wird.

12. Verfahren zur Aktivierung einer Halbleiterstörstelle nach einem der voranstehenden Ansprüche, bei dem das Licht eine Wellenlänge von 9.6 µm bis 9,8 µm besitzt.

Revendications

1. Procédé d'activation d'une impureté de semi-conducteur par irradiation d'un semi-conducteur contenant un élément principal de semi-conducteur et un élément d'impureté, par de la lumière pour l'activation de l'élément d'impureté, dans lequel :

l'élément principal de semi-conducteur est le carbure de silicium,
l'élément d'impureté est un élément choisi parmi l'aluminium, le bore et le gallium,
la lumière a une longueur d'onde supérieure à une longueur d'onde qui provoque une absorption à une limite de bande du semi-conducteur,
la longueur d'onde est telle que l'absorption de résonance est provoquée par une vibration caractéristique dans une liaison d'un élément constituant l'élément principal de semi-conducteur et l'élément d'impureté, et,
par utilisation de lumière, l'élément d'impureté

est activé par mise sélective en vibration d'une liaison entre l'élément d'impureté et l'élément constituant l'élément principal de semi-conducteur.

2. Procédé d'activation d'une impureté de semi-conducteur selon la revendication 1, dans lequel la lumière est appliquée après que l'élément d'impureté a été implanté dans l'élément principal de semi-conducteur.

3. Procédé d'activation d'une impureté de semi-conducteur selon la revendication 1, dans lequel le semi-conducteur est formé par implantation de l'élément d'impureté dans une couche mince comprenant l'élément principal de semi-conducteur ou dans un substrat comprenant l'élément principal de semi-conducteur.

4. Procédé d'activation d'une impureté de semi-conducteur selon la revendication 1, 2 ou 3, dans lequel la lumière a une longueur d'onde comprise entre 9,5 et 10 µm.

5. Procédé d'activation d'une impureté de semi-conducteur selon l'une quelconque des revendications précédentes, dans lequel la lumière est la lumière d'un laser.

6. Procédé d'activation d'une impureté de semi-conducteur selon la revendication 5, dans lequel :

la lumière du laser est focalisée sur un point focal adjacent à une surface du semi-conducteur, et
l'élément d'impureté dans une région prédéterminée dans le semi-conducteur est activé par balayage du semi-conducteur par la lumière laser.

7. Procédé d'activation d'une impureté de semi-conducteur selon la revendication 5, dans lequel :

la lumière laser est focalisée sur un point focal adjacent à une surface du semi-conducteur, et l'intensité d'irradiation de la lumière laser est réglée par réglage de la distance comprise entre le point focal et la surface du semi-conducteur.

8. Procédé d'activation d'une impureté de semi-conducteur selon la revendication 5, dans lequel :

la lumière laser est focalisée sur un point focal qui se trouve à la surface du semi-conducteur ou suffisamment proche pour qu'un panache soit formé, et
l'irradiation par la lumière laser est réalisée par détection du panache formé dans le cas où l'intensité d'irradiation de la lumière laser est accrue, et par réglage de l'intensité d'irradiation à une intensité telle que le panache commence à être détecté.

9. Procédé d'activation d'une impureté de semi-conducteur selon la revendication 5, dans lequel :

la lumière laser est focalisée sur un point focal adjacent à une surface du semi-conducteur, et l'irradiation par la lumière laser est réglée de manière que le point focal de la lumière laser ait une position comprise entre la source de lumière laser et la surface du semi-conducteur, la position étant à une distance prédéterminée de la surface du semi-conducteur.

10. Procédé d'activation d'une impureté de semi-conducteur selon la revendication 5, dans lequel :

la lumière laser est focalisée en un point focal à la surface du semi-conducteur ou suffisamment proche de cette surface pour qu'un panache soit créé, et
l'irradiation par la lumière laser est réalisée par détection d'un panache créé dans le cas où l'intensité d'irradiation de la lumière laser est accrue et par réglage de la lumière laser afin qu'elle soit focalisée à une position telle que le panache commence à être détecté.

11. Procédé d'activation d'une impureté de semi-conducteur selon l'une quelconque des revendications précédentes, dans lequel seule une région prédéterminée dans le semi-conducteur est irradiée sélectivement par la lumière à l'aide d'un organe de masque.

12. Procédé d'activation d'une impureté de semi-conducteur selon l'une quelconque des revendications précédentes, dans lequel la lumière a une longueur d'onde comprise entre 9,6 et 9,8 µm.

FIG. 1

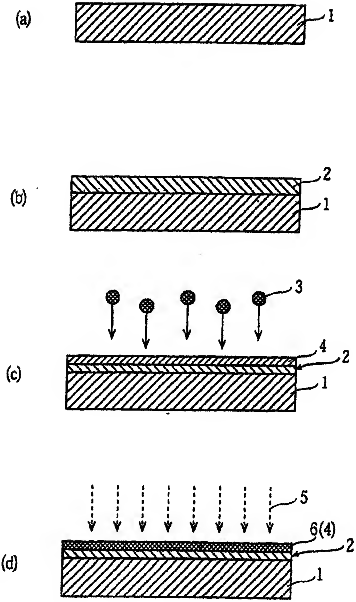
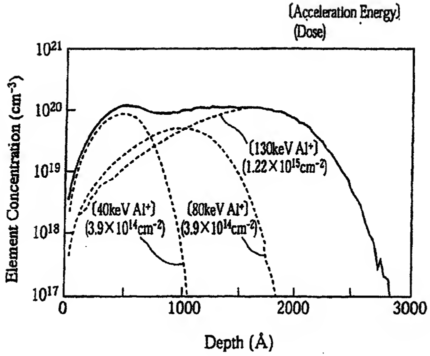


FIG. 2



(Acceleration Energy)
(Dose)
Element Concentration (cm^{-3})
10^{21}
10^{20}
10^{19}
10^{18}
10^{17}
(130keV Al^{+})
(1.22×10^{15}cm^{-2})
(40keV Al^{+})
(3.9×10^{14}cm^{-2})
(80keV Al^{+})
(3.9×10^{14}cm^{-2})
0
1000
2000
3000
Depth (Å)

FIG. 3

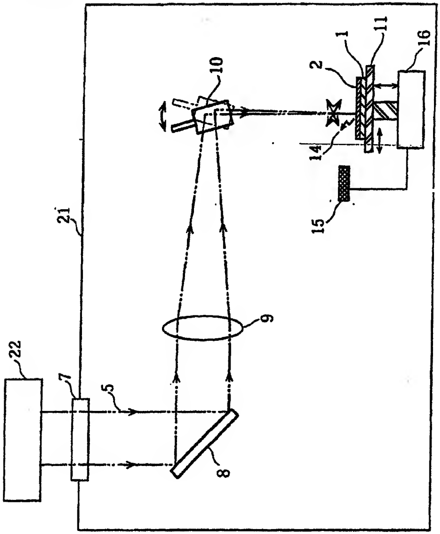


FIG. 4

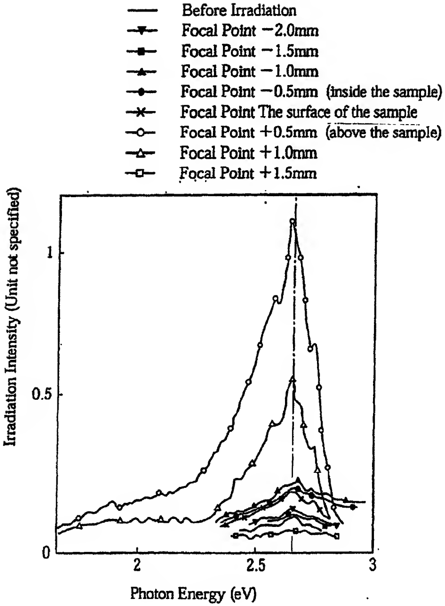

Before Irradiation
Focal Point −2.0mm
Focal Point −1.5mm
Focal Point −1.0mm
Focal Point −0.5mm (inside the sample)
Focal Point The surface of the sample
Focal Point +0.5mm (above the sample)
Focal Point +1.0mm
Focal Point +1.5mm
Irradiation Intensity (Unit not specified)
1
0.5
0
2
2.5
3
Photon Energy (eV)

FIG. 5

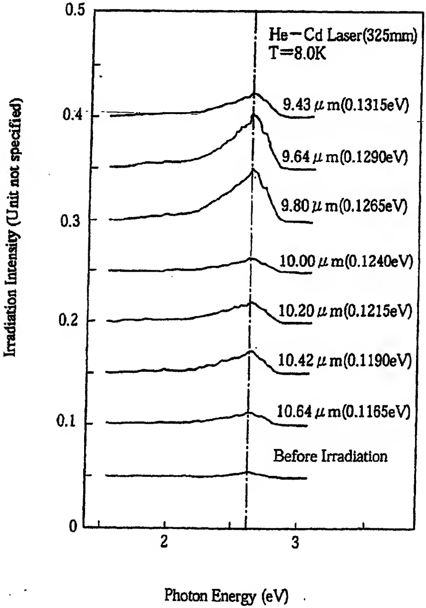

0.5
0.4
0.3
0.2
0.1
0
Irradiation Intensity (Unit not specified)
He−Cd Laser(325mm)
T=8.0K
9.43 μm(0.1315eV)
9.64 μm(0.1290eV)
9.80 μm(0.1265eV)
10.00 μm(0.1240eV)
10.20 μm(0.1215eV)
10.42 μm(0.1190eV)
10.64 μm(0.1165eV)
Before Irradiation
2
3
Photon Energy (eV)

FIG. 6

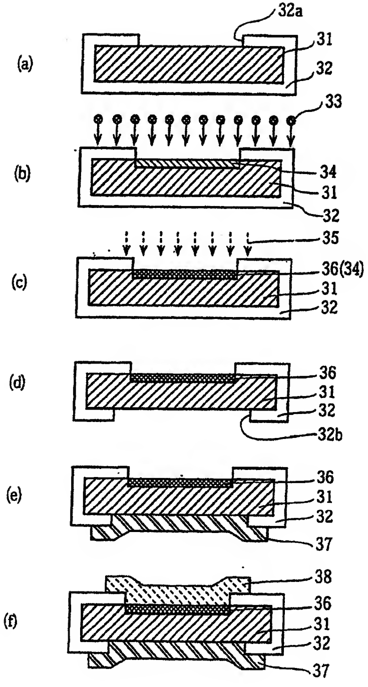
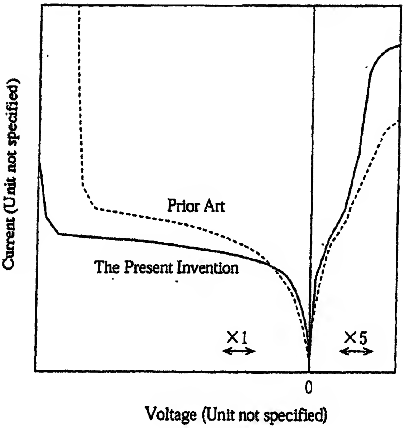

(a)
32a
31
32
33
(b)
34
31
32
35
(c)
36(34)
31
32
(d)
36
31
32
32b
(e)
36
31
32
37
(f)
38
36
31
32
37

FIG. 7


Current (Unit not specified)
Prior Art
The Present Invention
×1
×5
0
Voltage (Unit not specified)